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Analytical Study on the Influence of Rib Beams on the Stability of RCC Dome Structures

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ABSTRACT

Dome systems are space structures which cover a big area with minimum support. It is a doubly curved shell structure. Dome is stronger, stable and sturdy than any other singly curved shell structures which are relevant to many civil engineering structures like an auditorium, exhibition hall, industrial structures, pinnacle protection of ground water tank etc. Modern concrete shell domes can be constructed to the ratio (thickness-to-radius) of 1:800, using concrete and wire mesh and they are safe, aesthetically pleasing and long-lasting. The main aim of this study is to analyze the behaviour and strength of modern-day thin spherical shell domes made of concrete with and without rib beams using finite element technique with the help of SAP2000 software. The work consists of the erection of round domes with a massive diameter of 50m, 100m, and 150m with and without rib beams and a shell thickness of 15cm. Analytical study on all models was performed to study the influence of the big diameter and thickness of shell dome on stress distribution.

Keywords: Semi-spherical dome; Non-linear analysis; Stress distribution; Rib beams; SAP2000.

1. INTRODUCTION

"Dome" is originated from a Latin word "domus" which was used via renaissance to label the respected house because of the form of its roof. Dome structures made a footprint in the structures of civilizations from ancient times. Dome is a very strong and doubly curved shell shape structure. A round shell roof defines its geometry by way of upward thrust and span it possesses. Lower the upward push, larger will be the radius of curvature. Concrete is strong in compression, so makes it an ideal material for shell rooftop development. The floor of a dome may be a part of a circle or a paraboloid, and it may comprise of a patchwork of one-of-a-kind surfaces. In the modern days, skinny shell systems are adapted in many structures of innovation, for example, space vehicles, atomic reactors, weight vessels, mosques and meeting halls. From the attitude of engineering, the advancement of shell shape gives surprising conceivable effects and open doorways for the joined acknowledgement of practical, monetary and aesthetic viewpoints. Dome has excessive structural resistivity when properly built and can span huge open areas without interior supports. It is extra efficient and inherently strong systems via a distinctive feature of its spatial shape and load-carrying mechanism. In addition to the strong form, shell structures carry applied loads by using membrane movement, instead of the bending observed in framed structures. The membrane movement occurs in an aircraft, where normal and shear stresses are prevalent. It permits shell with a small thickness to absorb very huge forces with fairly low-pressure resultants and are capable of covering large spans with very small thicknesses. Dome shell consists of various geometrical shapes. When a section of a round curve revolves approximately in vertical diameter, a round dome is formed. Similarly, the elliptical dome is acquired with the aid of the revolution of an elliptical curve.

In the present study, concrete made models that agree with the nonlinear three-dimensional analysis of reinforced concrete members under response spectrum load are considered. These models assume the concrete as being a “linear elastic-perfectly plastic-brittle-fracture” material. The concrete under a triaxial stress state is assumed to crush or crack completely once the fracture is reached. The literature [1-11] was consulted for the study. The study was carried on designed spherical domes with a diameter of 50m, 100m and 150m. The domes were designed firstly with rib beams and secondly without rib beams. The thickness of the dome was adopted as 15 cm. A response spectrum analysis was carried out on the designed domes in SAP2000 software and all models were analyzed for the large diameter and thickness of shell dome on stress distribution.

2. MATERIAL PROPERTIES

In developing a finite element model for reinforced concrete members of the dome structure in SAP2000 following two materials are considered: Concrete (Ec) = $5000\sqrt{fck}$ N/mm^2; Steel rebar (Es) = 2 x 105 N/mm^2. This study considers M30 grade concrete and Fe415 steel for designing dome shell and rib beam components.

2.1 Section Properties

The following section properties of various elements to be designed are considered:

- Shell element of 15cm thickness with a single layer of reinforcement.
- Rib beams of size 150mm x 150mm with 12mm diameter Fe415 high yield strength deformed (HYSD) rebar reinforcement.

3. MODELLING

The basic steps involved in designing and analysing the dome model in SAP2000 were as follows:

- Defining materials.
- Defining sections.
- Model creation.
- Meshing.
- Applying boundary conditions and loading.
- Running analysis and
- Results.

In this study, the non-linear analysis of the dome was carried out by creating a dome model in SAP2000 software. Firstly, the domes of diameter 50m, 100m and 150 m with a rib beam of size 150mmx150mm were designed. The shell thickness for the domes being 15cm, and they were reinforced single layered. The rib beams were doubly reinforced with 12mm diameter Fe415 HYSD rebar.

All the shell members and the supporting rib beams were internally meshed with each other using the meshing tool of SAP2000. This was done so that the whole dome model consisting of shell elements and the beam elements behave as a single monolithic model and the stress distribution and displacements among the adjacent members take place uniformly. The dome structure was supported at the base with hinge supports, provided at equal intervals throughout the dome base. These hinge supports could be idealized as the below supporting mechanism structure on which the dome rests. Figure 1 depicts a sample dome structure model designed with rib beams. Similarly, the domes of diameter 50m, 100m, 150m were designed. Figure 2 depicts a sample dome structure model designed without rib beams

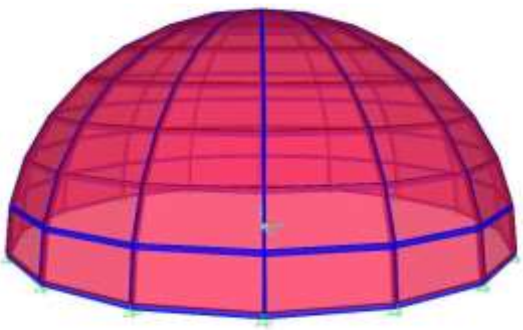

Figure 1. Dome designed with rib beams

Figure 2. Dome designed without rib beams

3.1 Loading conditions

After the dome was modelled, the next important step was applying loading conditions. In this case, initially, the bottom of the dome was restrained with hinge supports. This will restrict the dome to initiate movement when the loading is applied and help in resisting the load. In defining the loading conditions on the dome, three loads were taken into consideration. Firstly, the dead load of the whole dome. Secondly, loads at the nodes of the dome when subjected to the analysis to observe the dynamic response. Lastly, a default response spectrum function will be taken in software following Indian Standard codes to carry out non-linear analysis on dome structure.

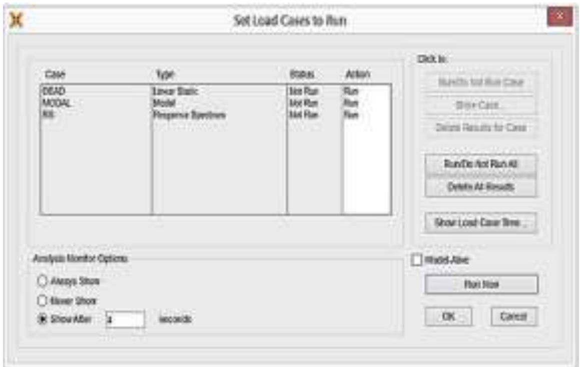

Figure 3. Load cases considered for analysis

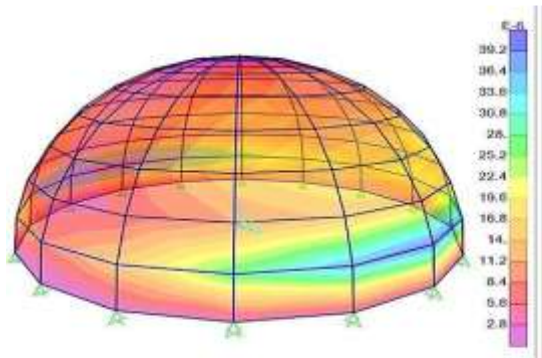

Figure 5. 50m diameter with rib beams

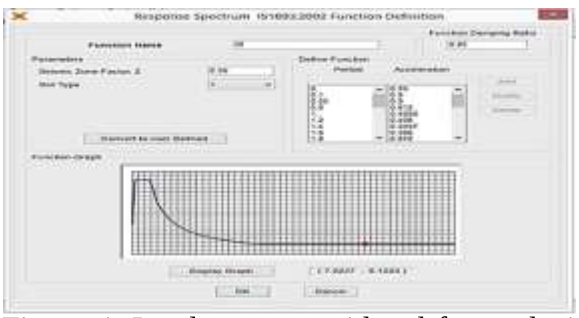

Figure 4. Load cases considered for analysis.

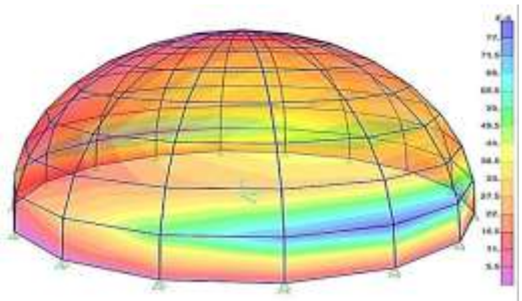

Figure 6. 100m diameter with rib beams

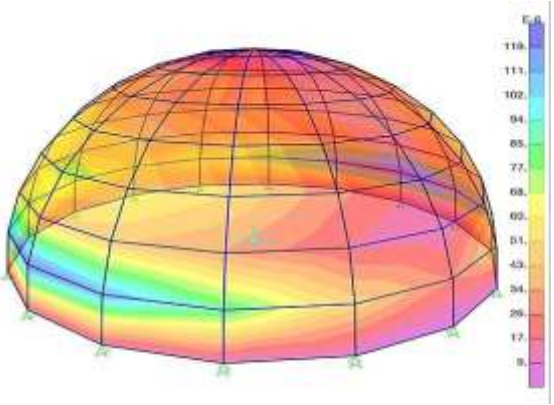

Figure 7. 150m diameter with rib beams.

4. OBSERVATIONS

4.1 Stress contours of dome having diameter 50m, 100m and 150m with rib beams

In the above Figures 5, 6 and 7 we have shown the stress contours of dome for 50m, 100m, and 150m diameter with rib beams.

4.2 Stress contours of dome having diameter 50m, 100m and 150m without rib beams

In the below Figures 8, 9 and 10 we will show the stress contours of dome for 50m, 100m and 150m diameter without ribs.

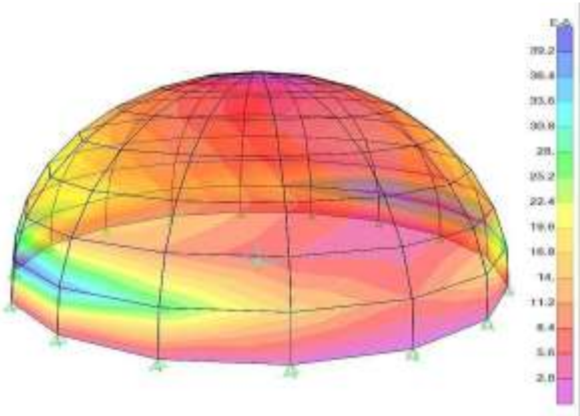

Figure 8. 50m diameter without rib beams

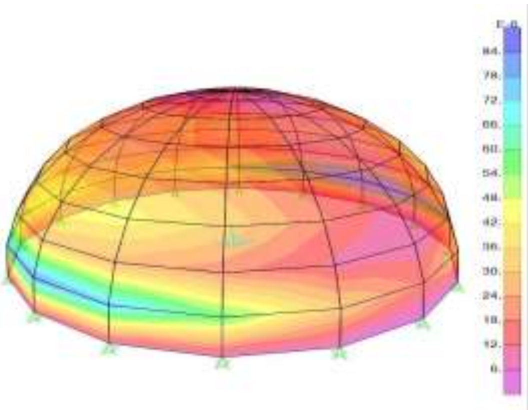

Figure 9. 100m diameter without rib beams

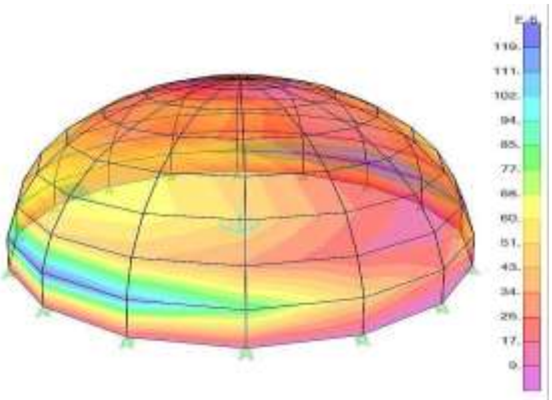

Figure 10. 150m diameter without rib beams

4.3 Moment contours of dome having diameter 50m, 100m and 150m without rib beams

The moment contours of respective domes of diameter 50m, 100m and 150m with rib beam is shown in Figure 11, 12 and 13. Similarly, the moment contours of respective diameter domes without ribs are shown in Figure 14, 15 and 16.

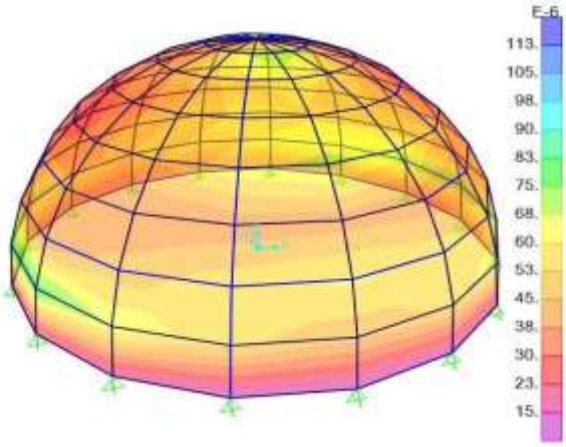

Figure 11. 50m diameter with rib beams

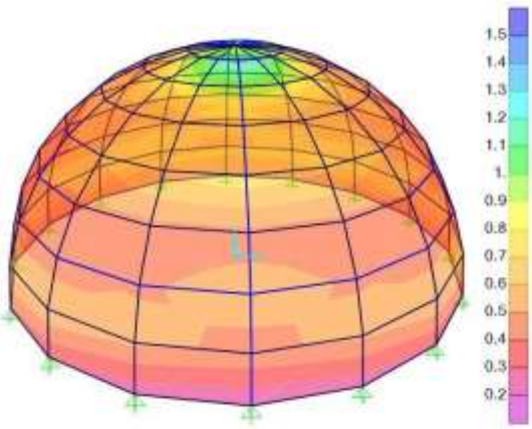

Figure 12. 100m diameter with rib beams

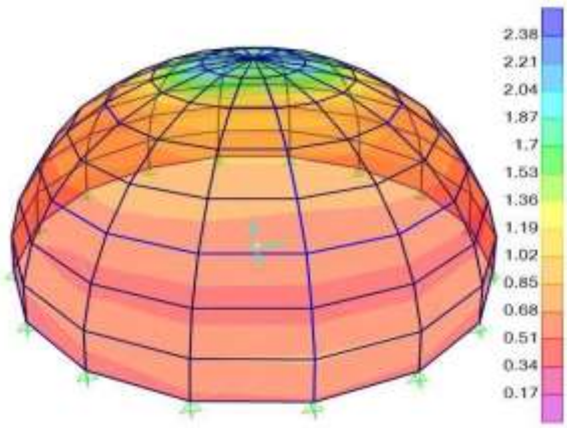

Figure 13. 150m diameter with rib beams

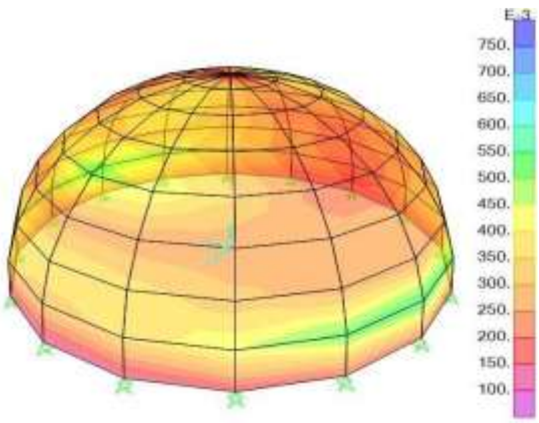

Figure 14. 50m diameter without rib beams

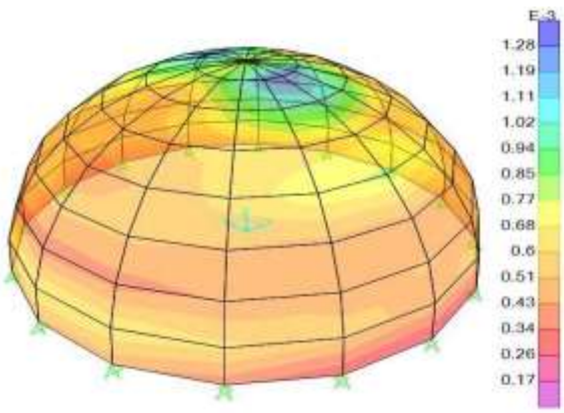

Figure 15. 100m diameter without rib beam.

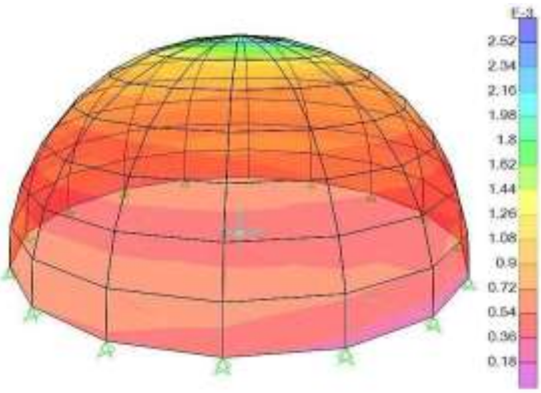

Figure 16. 150m diameter without rib beams

The analysis results of the dome under response spectrum loads, acting as seismic loads using SAP2000 software are presented in the Table 1-4.

Table 1. Depicting maximum stresses in a dome with and without rib beams

Maximum Stress		
Dome diameter (m)	**With Rib beam (kN/m^2)**	**Without Rib beam (kN/m^2)**
50	0.081	0.54
100	1.278	1.301
150	1.966	1.987

Table 2. Depicting minimum stresses in a dome with and without rib beams

Minimum Stress		
Dome diameter (m)	**With Rib beam (kN/m^2)**	**Without Rib beam (kN/m^2)**
50	0.001	0.005
100	0.035	0.039
150	0.059	0.058

Table 3. Depicting maximum moments in a dome with and without rib beams

Maximum Moment		
Dome diameter (m)	**With Rib beam (kN/m^2)**	**Without Rib beam (kN/m^2)**
50	0.117	0.8
100	1.463	1.345
150	2.458	2.643

Table 4. Depicting minimum moments in a dome with and without rib beams

Minimum Moment		
Dome diameter (m)	**With Rib beam (kN/m^2)**	**Without Rib beam (kN/m^2)**
50	0.008	0.06
100	0.145	0.147
150	0.141	0.14

The load was applied on each dome for various diameter variations and stresses and the corresponding moments were noted down. The values obtained from finite element analysis using SAP2000 software were then plotted in the graphical format as shown in Figure 17-20 to give us a better understanding of the stress in (kN/m^2) and moment (kNm) variations with respect to the applied load. The dome diameter is in meters.

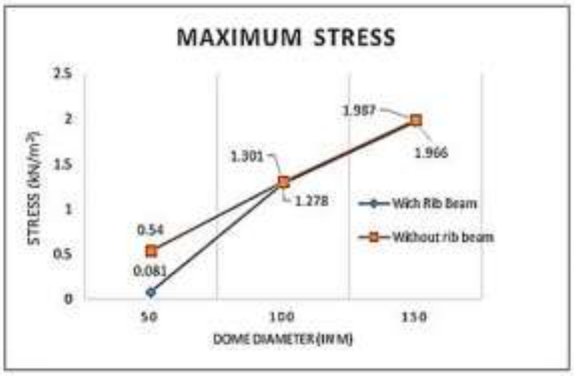

Figure 17. Max. Stress vs dome diameter

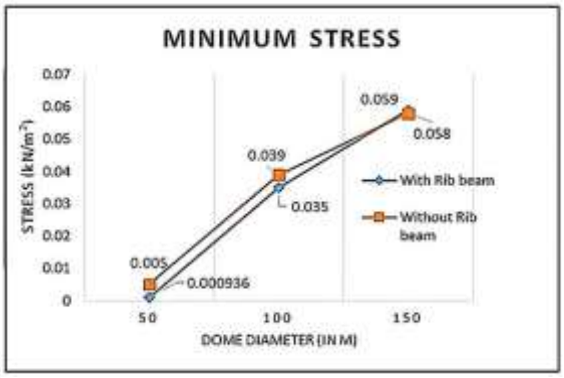

Figure 18. Min. Stress vs dome diameter

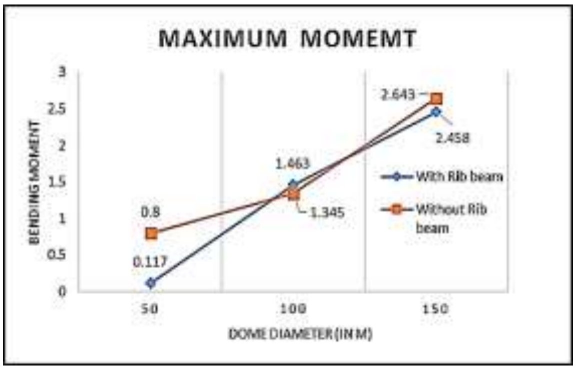

Figure 19. Max. Moment vs dome diameter

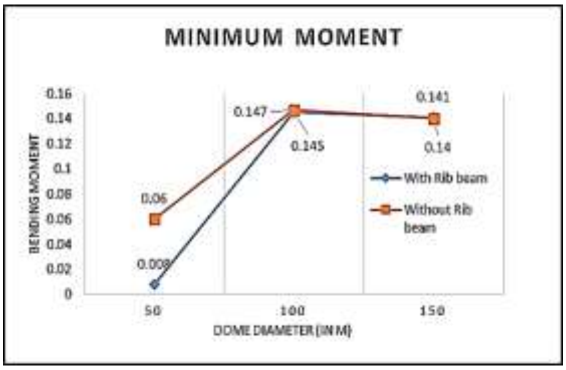

Figure 20. Min. moment vs dome diameter

5. RESULTS AND DISCUSSION

5.1 Dome with 50m diameter and with rib beams

- When the dome was subjected to response spectrum load, the maximum stress was noted to be 0.081 kN/m^2 and the minimum stress was noted to be 0.001 kN/m^2.
- When the dome was subjected to response spectrum load, the maximum moment was noted to be 0.117 kN/m^2 and the minimum moment was noted to be 0.008 kN/m^2.

5.2 Dome with 50m diameter and without rib beams

- When the dome was subjected to response spectrum load, the maximum stress was noted to be 0.54 kN/m2 and the minimum stress was noted to be 0.005 kN/m^2.

- When dome was subjected to response spectrum load, the maximum moment was noted to be 0.8 kN/m^2 and the minimum moment was noted to be 0.06 kN/m^2.

5.3 Dome with 100m diameter and with rib beams

- When the dome was subjected to response spectrum load, the maximum stress was noted to be 1.278 kN/m^2 and the minimum stress was noted to be 0.035 kN/m^2.
- When the dome was subjected to response spectrum load, the maximum moment was noted to be 1.35 kN/m^2 and the minimum moment was noted to be 0.145 kN/m^2.

5.4 Dome with 100m diameter and without rib beams

- When the dome was subjected to response spectrum load, the maximum stress was noted to be 1.301 kN/m^2 and the minimum stress was noted to be 0.039 kN/m^2.
- When the dome was subjected to response spectrum load, the maximum moment was noted to be 1.46 kN/m^2 and the minimum moment was noted to be 0.147 kN/m^2.

5.5 Dome with 150m diameter and with rib beams

- When the dome was subjected to response spectrum load, the maximum stress was noted to be 1.966 kN/m^2 and the minimum stress was noted to be 0.059 kN/m^2.
- When the dome was subjected to response spectrum load, the maximum moment was noted to be 2.458 kN/m^2 and the minimum moment was noted to be 0.141 kN/m^2.

5.6 Dome with 150m diameter and without rib beams

- When the dome was subjected to response spectrum load, the maximum stress was noted to be 1.987 kN/m^2 and the minimum stress was noted to be 0.058 kN/m^2.
- When the dome was subjected to response spectrum load, the maximum moment was noted to be 2.643 kN/m^2 and the minimum moment was noted to be 0.14 kN/m^2.

6. CONCLUSIONS

This study aims to analyse the behaviour and strength of modern-day thin spherical shell domes made of concrete with and without rib beams by the use of finite element technique thru SAP2000 software. The work consists of the erection of round domes with a massive diameter of 50m, 100m and 150m with a thickness of 15cm. The analysis was conducted on three cases in each category to validate the results. Based on the analytical study following conclusions were drawn:

- In 50m diameter domes, the domes without rib beams showed significant in-plane maximum and minimum stress of the order of +566.67% and +434.19% respectively as well as maximum and a minimum bending moment of the order of +583.76% and +650% respectively compared to domes with rib beams.

- In 100m diameter domes, the domes without rib beams showed less difference of the order of +1.8% in maximum in-plane stress and significant +11.435% in minimum stress as compared to domes with rib beams.
- In 100m diameter domes, the domes without rib beams showed significant in-plane maximum and a minimum bending moment of the order of +8.15% and +1.37% respectively compared to domes with rib beams.
- In 150m diameter domes, the dome without rib beams showed +1.06% greater in-plane maximum stress and -1.69% less in-plane minimum stress as compared to domes with rib beams. Also, the domes without rib beams showed +7.52% greater maximum bending moment and -0.70% lesser minimum bending moments compared to domes with rib beams.
- The shear carrying capacity is in direct correlation with dome diameter with rib beams. But as the diameter increases domes without rib beams starts showing less in-plane minimum stress.
- The greater influence of rib beams was evident in 50m diameter domes in both in-plane maximum and minimum stresses and moment followed by 100m and 150m diameter domes.

CONFLICT OF INTERESTS

The author would like to confirm that there is no conflict of interests associated with this publication and there is no financial fund for this work that can affect the research outcomes.

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